(54) **Scanning electron microscope**

(57) A scanning electron microscope comprises an objective lens (6) for forming a lens magnetic field on the side of a sample (7). The image of the sample is observed by detecting secondary electrons (9) from the sample (7) on the upper side of the objective lens (6). Accelerating electrode means (10a, 10b) supplied with a positive potential is arranged along the electron beam passage of the objective lens (6). An electric field correction electrode (11) supplied with a negative potential is disposed outside the accelerating electrode means (10a, 10b) or on the side of the sample (7). Image observation with high resolution is realised even when the sample (7) is inclined.

FIG. 1
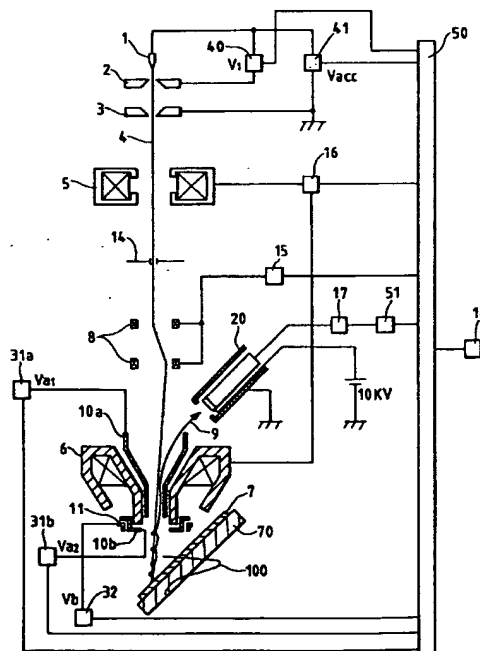
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Description

Background of the Invention;

Field of the Invention;

This invention is related to a scanning electron microscope, and particularly to a scanning electron microscope having a mechanism for including.

Description of the Prior Art;

As a method for obtaining a high resolution image by a scanning electron microscope, conventionally have been known a method of so-called an inlens type wherein a sample is disposed between magnetic poles of an objective lens and a method wherein an outer size of a magnetic pole in the objective lens is made smaller than an inner size of the objective lens, and the lens magnetic field is generated on the side of the sample by protruding an under surface of the inner magnetic pole to the sample side as same as the under surface of the outer magnetic pole or more.

As is described in U. S. Patent No 4,713,543, also known is a method for reducing an aberration of the objective lens wherein a high positive potential is applied by arranging electrodes in axisymmetry on an electron beam passage from an electron beam gun to the objective lens, and wherein energy of a primary electrons beam at the time of passing the objective lens is made higher than another energy (final accelerating voltage) at the time of reaching the sample. In the above method, a secondary electrons generated from the sample is wound up by the magnetic field of the objective lens or is accelerated by an applied voltage of the electrode arranged in the electron beam passage of the objective lens, and as a result, the secondary electrons moves to the upper part of the objective lens (the electronic source side). Therefore, it is necessary to detect the secondary electrons on the upper part of the objective lens. Especially, in the objective lens generating the lens magnetic field on the sample side, the secondary electrons that moves to the upper part of the objective lens emanates when the magnetic field of the objective lens extincts.

To detect such a secondary electrons efficiently, the electrode (accelerating electrode) for accelerating the secondary electrons is arranged to the primary electrons beam passage of the magnetic pole of objective lens, and a positive voltage is applied. However, in the above prior art, an electric field occurs between the sample and the accelerating electrode by the positive voltage applied to the electrode (accelerating electrode) that accelerates the secondary electrons, or by another positive voltage applied to the electrode (accelerating electrode) that accelerates the primary electrons beam for the purpose of reducing the aberration.

When the sample is not inclined, the electric field between the accelerating electrode and the sample becomes axisymmetric. Consequently, due to the effects of the electric field and the magnetic field of the objective lens, the secondary electrons occurred from the sample is efficiently guided to a secondary electrons detector on the upper part of the objective lens. When the sample is inclined, a distance between the accelerating electrode and the sample changes and places of a strong electric field and a weak one occur. Therefore, the secondary electrons is deflected in the direction that orthogonalizes an optic axis. As a result, there is a fault that the secondary electrons generated from the sample does not reach the secondary electrons detector arranged on the upper part of the objective lens by colliding with a wall on the way of passing the objective lens. This asymmetric field becomes a cause of the aberration. When the electrode is arranged along the electron beam passage of the objective lens magnetic pole, a diameter of the lower part of the objective lens (horizontal part) becomes large. Therefore, when the sample is inclined by wide angles high angle, the distance (working distance) between the under surface of the objective lens and the sample become long, so that a resolution power reduces. On the other hand, an arranging the electrode to the lower part of the objective lens and an application of a negative voltage to this electrode are disclosed in Japanese Patent Granted Print No.60-9543 for example. Because the purpose of the above method is energy discrimination of the secondary electrons, it is necessary to make the voltage of the electrode 0 (zero) v in the image observation of ordinary secondary electrons without energy discrimination, the emanation of the secondary electrons after the magnetic field of the objective lens extincts cannot be repressed.

Summary of the Invention;

A main object of this invention is to provide a scanning electron microscope, which detects a secondary electrons occurred from a sample on the upper part of an objective lens, that realizes a short working distance having a high resolution observation without reducing an efficiency of the secondary electrons detection even if the sample is inclined.

Another object of this invention is to realize an automatic high resolution observation even when such an observation condition of the sample as an accelerating voltage of a secondary electrons beam or inclination angle is changeable.

A main feature of this invention is that an electrode for correcting an electric field is disposed outside the accelerating electrode of the secondary electrons close to the sample or a sample side, and a negative voltage is applied to this electrode for correcting the electric field.

Another feature of this invention is to automatically change the voltage to be applied to the above electrode in response to the voltage applied to the accelerating electrode of the above secondary electrons or the

inclined angle in the above sample.

The above objects, features, other objects and features of this invention are explained according to following examples.

Brief Description of the Drawings;

Fig. 1 shows a schematic cross-sectional view of an example of this invention.

Fig. 2 is an explanation of an influence give by an accelerating electrode and an electrode for correcting electric field on an image pickup sight.

Fig. 3 shows an electric potential distribution on the optic axis.

Fig. 4 is an explanation figure of an equipotential distribution and a secondary electrons orbit when no electrode for correcting electric field is disposed.

Fig. 5 is an explanation figure of an equipotential distribution and a secondary electrons orbit when a negative voltage is applied to the electrode.

Fig. 6 shows a relationship between a sample inclination angle and an applied voltage to each of the electrodes.

Fig. 7 and Fig. 8 show other examples of accelerating electrodes and electric field correction electrodes.

Fig. 9 shows an example wherein an accelerating electrodes are constituted by a magnetic body.

Fig. 10 shows another example wherein accelerating electrodes are constituted by a magnetic body.

Description of the Preferred Embodiment;

Before explaining a concrete constitution of this invention, the principle of this invention is explained. When a sample is inclined, a deflection of a secondary electrons by an electric field generated between an accelerating electrode to which a positive voltage is applied and the sample is offset by the deflection effect of the electric field occurred between the electric field correction electrode, which is arranged on the same axis with accelerating electrode, a negative voltage and the sample. Therefore, the secondary electrons is not deflected between the electrode and the sample, and the secondary electrons can enter the accelerating electrode without deflecting. As the internal electric potential of the accelerating electrode is axisymmetric, the secondary electrons entered into the accelerating electrode is accelerated without deflecting in the orthogonal direction of the optic axis. Therefore, the secondary electrons can be detected in the same state as the sample is not inclined.

Figs. 2a to 2c explain the above by the change of an image pickup sight of a scanning electron microscope. A conventional scanning electron microscope is shown in Fig. 2a which has the accelerating electrode, but does not have the electric field correction electrode of this invention, wherein image pickup sight 80 when the inclination angel of the sample is zero, and light area 81 is in the sight center. When the sample is inclined in this state, light area 81 is deviated from the center of sight 80 as is shown by an arrow in Fig. 2b. This is because the electric field between the accelerating electrode and the sample becomes nonaxisymmetric by inclining the sample so that the secondary electrons occurred from the sample is deflected by the nonobjective electric field. However, when both the electric field correction electrode and the accelerating electrode are disposed and the negative voltage is applied to the electric field correction electrode, light area 81 that has deviated to the corner of the sight moves toward the sight center as shown by arrow in Fig. 2c. When the negative voltage is set to a proper value, light area 81 can return to the sight center again, so that the sample can be observed under the similar condition of Fig. 2a.

In the case where the electric field correction electrode is provided, even if the sample is inclined, an electric potential distribution close to a beam irradiation point of the sample does not become asymmetrical so that there is an advantage that an astigmatism about a primary electrons beam is repressed. A deflection action of the secondary electrons produced at the time of the sample inclination depends on the applied voltage of the accelerating electrode closest to the sample. When the negative voltage applied to the electric field correction electrode is responsive to the applied voltage of the accelerating electrode, the voltages are controlled so that a predetermined relationship (relationship to offset the deflection action of the secondary electrons) comes into existence. By the above relationship, highly efficient secondary electrons detection can be done without deflection action by the secondary electrons at the time of the sample inclination, even though the applied voltage of the accelerating electrode is changed according to an accelerating voltage or working distance.

When the accelerating electrode closest to the sample among the electrodes is constituted by a magnetic body so as to function as a magnetic pole of an objective lens, a lower diameter of the objective lens can be made smaller, and high resolution power is obtained because of shortening the working distance at the time of the sample inclination.

This invention is explained in detail by a concrete example as follows.

Fig. 1 is a structure diagram of an example of the scanning electron microscope according to the present invention. Voltage V1 is applied between cathode 1 and first anode 2 from high-voltage control power source 40 controlled by micro processor (CPU) 50, and a fixed emission current is drawn from cathode 1. Accelerating voltage Vacc is applied between cathode 1 and secondary anode 3 from a high-voltage control power source controlled by CPU 50, and primary electrons beam 4 emitted from cathode 1 is accelerated to voltage Vacc. Primary electrons beam moves towards the lens system in the later step. Primary electrons beam 4 is focused onto sample 7 as a minute spot by focusing lens 5 and objective lens 6 that are controlled in lens control power

16, and primary electrons beam 4 is scanned two-dimensionally with deflection coil 8 on the surface of sample 7. The scanning signal of deflection coil 8 is controlled by deflection control circuit 15 according to an observation magnification. The focusing angle (beam divergence angle) of the primary electrons beam is decided by throttle 14 of the objective lens. Sample stage 70 that supports sample 7 is provided with functions for moving the sample in a horizontal direction and for inclining the sample.

Axisymmetric accelerating electrodes 10a and 10b are arranged on an electron beam passage of objective lens 6, to which positive voltages Va1 and Va2 are applied by voltage control power sources 31a and 31b. After primary electrons beam 4 is further accelerated by voltages Va1 and Va2 applied to accelerating electrodes 10a and 10b, primary electrons beam 4 is decelerated to former energy (Vacc) between objective lens 6 and sample 7 and is irradiated to sample 7. The magnetic pole of objective lens 6 has a hole diameter of an outer magnetic pole which is larger than that of an inner magnetic pole and the tip of the inner magnetic pole is more protruded to the sample than that of the outer magnetic pole, so as to generate lens magnetic field 100 at the sample side. When positive voltages Va1 and Va2 are applied to accelerating electrodes 10a and 10b, respectively, primary electrons beam 4 passes through objective lens magnetic field 100 with energy higher than Vacc, so that the lens aberration is reduced.

Secondary electrons 9 generated from sample 7 by irradiating electron beam 4 is trapped by the magnetic field of objective lens 6 and moves towards the upper side of the objective lens. After being accelerated by accelerating electrode 10b, the electron is focused by the action of an electrostatic lens formed in the gap between accelerating electrode 10a and accelerating electrode 10b. Therefore, secondary electrons 9 does not emanate in the area where not influenced by the magnetic field of the objective lens, and secondary electrons 9 is detected by secondary electrons detector 20 after moving towards the upper part of objective lens 6. The electrostatic lens can be formed in the boundary area even when either voltage Va1 or Va2 is higher or both are equal. Voltages Va1 and Va2 are set suitably according to the values of accelerating voltage Vacc and the value of the working distance. The signal of secondary electrons detector 20 is taken into image memory 51 through signal amplifier 17 and is displayed as an expansion image of the sample on image display 18. Each control circuit controlling the components of the electronic optic system and the control power source are central-controlled by above CPU 50.

Axisymmetric electric field correction electrode 11 is arranged to the outside of accelerating electrode 10b provided to objective lens 6 and is applied with negative voltage Vb by control power 32. Voltage Vb of electric field correction electrode 11 is set to the value so as to offset the deflection action resulted from accelerating electrode 10b when sample 7 is inclined. The relation-ship between Vb and Va2 that offsets the deflection action of this secondary electrons can be in advance determined by experiments or simulation and can be set by control CPU 50 to fulfill the relationship.

The action of electric field correction electrode 11 is explained according to Fig. 3, Fig. 4 and Fig. 5.

Fig. 3 shows a cross section of the objective lens at the left side and the electric potential distribution on the optic axis $\underline{o}$ at the right. The electric potential of the position of sample 7 is 0 (zero). The electric potential on the optic axis $\underline{o}$ close to sample 7 changes according to voltage Vb applied to electric field correction electrode 11. The area where the electric potential gradient exists acts as the electrostatic lens, and the area conducts the action that focuses the secondary electrons occurred from sample 7. Curve $\underline{a}$ in the figure shows the electric potential distribution when there is no electric field correction electrode 11. The electric potential distribution on the optic axis $\underline{o}$ changes as shown by curves $\underline{b}$ and $\underline{c}$ as the absolute value of negative voltage Vb applied to electric field correction electrode 11 increases. Curve $\underline{b}$ shows the electric potential distribution when the value of voltage Vb is proper and curve $\underline{c}$ the electric potential distribution when the absolute value of voltage Vb is too large, respectively. Because the area where the electric potential becomes negative is formed on the optic axis $\underline{o}$ in electric potential distribution $\underline{c}$, the secondary electrons occurred from the sample cannot be pumped up into objective lens 6, therefore the secondary electrons cannot be detected.

Fig. 4 shows an equipotential lines at the time of the sample inclination without electric field correction electrode 11. As is shown in Fig. 4, when there is no electric field correction electrode 11, equipotential lines 101 at the time of the sample inclination becomes asymmetrical because the equipotential lines protrudes in the inclined direction of sample 7. Therefore, secondary electrons 9 occurred from sample 7 is not only accelerated in the direction of the optic axis, but also receives a deflection action in the orthogonal direction (direction of sample inclination) of the optic axis. As a result, almost all of secondary electrons 9 collide with inner wall of accelerating electrodes 10a and 10b, and do not reach secondary electron detector 20.

Fig. 5 shows equipotential lines 101 at the time of the sample inclination, wherein electric field correction electrode 11 is arranged outside accelerating electrode 10b and negative voltage Vb is applied. As negative voltage Vb is applied to electric field correction electrode 11, a direction of the secondary electrons deflected by negative voltage Vb at the time of the sample inclination is opposite to a direction of accelerating electrode 10b deflected by positive voltage Va2. Consequently, by selecting the value of voltage Vb so as to offset the deflection action between the secondary electrons of negative voltage Vb and secondary electrons of positive voltage Va2, the axisymmetry of the electric potential distribution of the sample vicinity of both electrodes is improved as shown in Fig. 5. Second-

ary electrons 9 move towards the upper part of objective lens 6 and is detected efficiently by secondary electron detector 20 without being deflected in the direction that secondary electrons 9 orthogonalize the optic axis.

Fig. 6 is a diagram showing an example of the applied voltage to each electrode, wherein the vertical axis shows the applied voltage of the electrode and the horizontal axis shows sample inclination angle. Fig. 6 also shows the relationship between voltage Va1, Va2 and Vb that are applied to each of electrodes 10a, 10b and 11 and the sample inclination angle when accelerating voltage Vacc is 1 kV. It also shows the relationship between voltage V'a1, V'a2 and V'b that are applied to each of electrodes 10a, 10b and 11 and the sample inclination angle when acceleration voltage Vacc is 10 kV. While voltages Vb and V'b are negative, the values are shown by absolute values for simplification in Fig. 6. When accelerating voltage Vacc is 1 kV, a magnetic field intensity of the objective lens that is necessary for focusing the primary electrons beam is small and the magnetic field intensity leading the secondary electrons, which occurred from the sample, to the secondary electron accelerating electrode of the objective lens is also weak. Therefore, applied voltage Va2 of secondary electron accelerating electrode 10b closest to the sample needs to set to the value higher than value V'a2 to compensate for the weakness of the magnetic field of objective lens 6 when the accelerating voltage is 10 kV. That is, voltage Vb of electric field correction electrode 11 is set to be high when accelerating voltage Vacc is 1 kV, but is set to low value V'b when accelerating voltage Vacc is 10 kV.

Since optimum value of the applied voltage of secondary electron accelerating electrode 10b depends on both the distance between sample 7 and accelerating electrode 10b and the strength of the magnetic field between them, the optimum condition is found out for every accelerating voltage Vacc and the working distance. On the other hand, applied voltage Vb of electric field correction electrode 11 depends on applied voltage Va2 of accelerating electrode 10b closest to sample 7, and after deciding applied voltage Va2 to accelerating electrode 10b, the optimum value is determined so as to avoid the loss of the secondary electrons due to the sample inclination. As applied voltage Va1 to other accelerating electrode 10a that are not close to the sample does not change in accordance with accelerating voltage Vacc and the working distance, applied voltage Va1 can be made a constant value. This is because the energy of secondary electrons 9 does not depend on accelerating voltage Vacc or the working distance.

In the case where the sample inclination angle is in the range from 0 (zero) to around 45° , even if applied voltage Vb to electric field correction electrode 11 is made constant, the secondary electrons occurred from the sample is efficiently guided to secondary electron detector 20 so that a high resolution image can be obtained. However, when further enlarging the sample inclination, it is useful for highly efficient detection of the

secondary electrons to control voltage Vb applied to electric field correction electrode 11 according to the sample inclination angle, as is shown in Fig. 6.

The relationships described above can be obtained by experiments or numerical value simulations and can be memorized in the form of relational expressions or of tables. The relationships include:

(1) Optimum value Va2 for accelerating voltage Vacc and the working distance;
(2) Relationship between Va2 and Vb to offset the deflection action of the secondary electrons at the time of the sample inclination; and
(3) Optimum voltage Vb applied to the large sample inclination angle. CPU 50 most suitably controls power 31b and 32 by referring to those relational expressions or tables.

Next, explained is another example of the accelerating electrode and the electric field correction electrode that are arranged along the electron beam passage of the objective lens.

Fig. 7 is an example of accelerating electrodes 10a and 10b that are overlapped partially. In this case, it is necessary to make a difference between applied voltage Va1 to accelerating electrode 10a and applied voltage Va2 to accelerating electrode 10b to form the electrostatic lens at the boundary between both accelerating electrodes 10a and 10b.

Fig. 8 is an example wherein one accelerating electrode 10 is disposed along the electron beam passage of objective lens 6. In this case, electric field correction electrode 11 is positioned below the inner magnetic pole of objective lens 6. In case of this example, there is a limit of the function that suppresses an emanation of the secondary electrons, the range of corresponding accelerating voltage Vacc or the working distance is limited. In this example, the flexibility of adjustment is limited as compared with a case that 2 or more accelerating electrodes are disposed, but a high resolution observation can be done in the state that the sample is inclined as same as other examples.

Fig. 9 is an example of accelerating electrode 10b constituted by a magnetic body. This electrode 10b of magnetic body is connected magnetically with inner magnetic path 6a of objective lens 6, and it functions as the inner magnetic pole of objective lens 6. Electric field correction electrode 11 is arranged so as not to disturb the inclination of the sample at outer electrode 10b of magnetic body. According to this example, the under surface of accelerating electrode 10b becomes the lower surface of the objective lens, and the high resolution observation can be done in a short working distance even if the sample is inclined. As shown in Fig. 10, magnetic pole 10b of magnetic body can be made a structure that covers an upper part with inner magnetic path 6a for improving the assembling precision of objective lens 6 to inner magnetic path 6a.

According to this invention, the short working dis-

tance can be realized even if the sample is inclined by wide angles, and a lens aberration can be made small. Since a high detection efficiency of the secondary electrons is acquired, the high resolution observation can be done by inclining the sample by wide angles.

Claims

1. A scanning electron microscope comprising

   a focusing lens system (5) for focusing a primary electron beam (4) onto a sample (7),
   an electron beam deflecting device (8) for two-dimensionally scanning said primary electron beam (4) on said sample (7),
   an objective lens (6) for forming a magnetic field on the side of said sample (7),
   accelerating electrode means (10a, 10b) supplied with a positive voltage and arranged at an electron beam passage of said objective lens (6), and
   an electric field correction electrode (11) supplied with a negative voltage and arranged outside that part of said accelerating electrode means (10a, 10b) which is closest to said sample (7) or arranged on the side of said sample (7).

2. The microscope of claim 1, wherein said accelerating electrode means (10a, 10b) is formed symmetrically with respect to the centre axis on said electron beam passage.

3. The microscope of claim 1 or 2, wherein a plurality of accelerating electrodes (10a, 10b) are disposed along said electron beam passage or on the side of said sample (7), and said electric field correction electrode (11) is arranged outside that accelerating electrode (10b) which is nearest to said sample (7).

4. The microscope of claim 3, wherein the accelerating electrode (10b) positioned closest to said sample (7) is constituted by a magnetic body, thereby additionally providing an objective lens function.

5. The microscope of any preceding claim, wherein said electric field correction electrode (11) is formed symmetrically with respect to the centre axis on said electron beam passage.

6. The microscope of any preceding claim, wherein said electric field correction electrode (11) is changed according to the voltage applied to said accelerating electrode means (10a, 10b).

7. The microscope of any of claims 3 to 6, including means for changing the voltage applied to said electric field correction electrode (11) according to the voltage applied of said accelerating electrode (10b) closest to said sample (7).

8. The microscope of any preceding claim, including means for changing the voltage applied to said electric field correction electrode (11) according to the inclination angle of said sample (7).
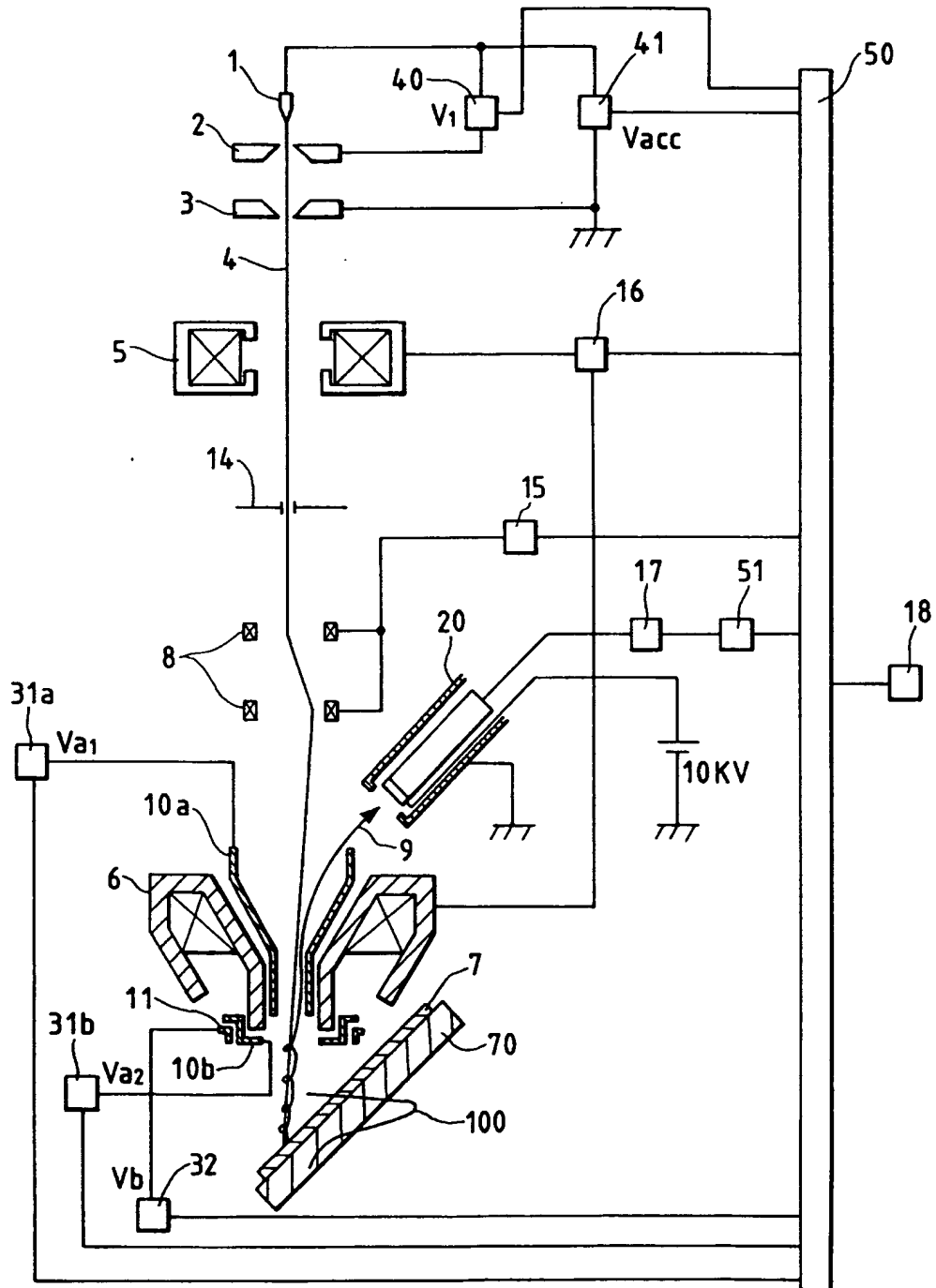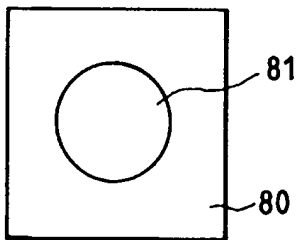
FIG. 1

FIG. 2a

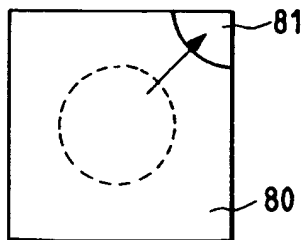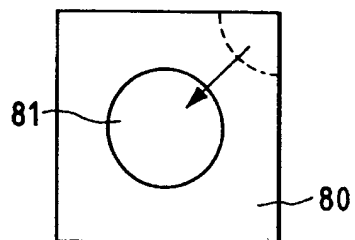
FIG. 2b

FIG. 2c

FIG. 3

FIG. 4

FIG. 5

FIG. 6

FIG. 7

FIG. 8

FIG. 9

FIG. 10

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EUROPEAN SEARCH REPORT

European Patent Office

Application Number
EP 96 11 0236

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X	US-A-4 330 707 (MANZKE KLAUS D) 18 May 1982 * column 2, line 50 - column 4, line 3; figure 1 *	1,2,6-8	H01J37/28 H01J37/244 H01J37/153 H01J37/26 H01J37/256 H01J37/04 H01J37/147 G01R31/305
X	PATENT ABSTRACTS OF JAPAN vol. 95, no. 003 & JP-A-07 073841 (HITACHI LTD), 17 March 1995, * abstract; figures 1,4,6 *	1-5	
X,D	US-A-4 713 543 (FEUERBAUM HANS-PETER ET AL) 15 December 1987 * abstract; figure 1 *	1,2	
A	EP-A-0 592 899 (HITACHI LTD) 20 April 1994 * column 5, line 50 - column 7, line 19; figures 2,6 *	1-8	
A	REVIEW OF SCIENTIFIC INSTRUMENTS, vol. 64, no. 10, 1 October 1993, pages 2905-2910, XP000400489 XIMEN J ET AL: "ELECTRON OPTICAL DESIGN OF A HIGH-RESOLUTION LOW-VOLTAGE SCANNING ELECTRON MICROSCOPE WITH FIELD EMISSION GUN" * pages 2908-2909: "A. Design and calculation for the XM-5 lens/SE collector system" * * figures 5,6 *	1-8	TECHNICAL FIELDS SEARCHED (Int.Cl.6) H01J G01R
A	US-A-4 831 266 (FROSIEN JUERGEN ET AL) 16 May 1989 * column 2, line 35 - column 4, line 2; figure 1 *	1-8	

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
MUNICH	31 October 1996	Bergado Colina, J

CATEGORY OF CITED DOCUMENTS
X : particularly relevant if taken alone
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EUROPEAN SEARCH REPORT

Application Number

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DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
A	US-A-4 812 651 (FEUERBAUM HANS-PETER ET AL) 14 March 1989 * column 2, line 30 - column 4, line 51; figures 1,2 * ---	1-8	
A	EP-A-0 561 584 (HITACHI LTD) 22 September 1993 * column 4, line 27 - column 6, line 10; figure 1 * * column 7, line 41 - column 8, line 1; figure 5 * -----	1-8	

TECHNICAL FIELDS
SEARCHED   (Int.Cl.6)

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
MUNICH	31 October 1996	Bergado Colina, J

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